RESEARCH

Quantitative Digital Subtraction Radiography (DSR) as an approach for evaluating crestal alveolar bone density changes around teeth following orthodontic tooth movement.

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Abstract

Aim: The aim of the present study was to retrospectively evaluate changes in bone density using DSR at the crestal and subcrestal regions of interproximal bone around posterior teeth (premolars and molars) before and after orthodontic treatment using digital OPGs.
Materials & Method : A total of 14 Pre and Post operative digital image pairs were obtained from the department of Orthodontics and 28 regions were sampled and analyzed. The selected patients were in the age group of 13-18 years. The mean duration of orthodontic treatment was 1.5 years. All pre and post operative radiographs were assessed at baseline and after completion of orthodontic treatment using DSR. All subtracted images were subsequently imported into The Image Tool® software to calculate the average density of Gray levels in the areas that showed changes in subtraction.
Results: Out of 28 test regions 23 regions (82.14%) showed an increase in bone density whereas 5 regions (17.85%) showed a decrease in bone density. The mean bone density of the ROIs was 151.18 (gray level = 151.18 ± 19.97 SD). A one sample t test for statistical significance was carried out. The difference of the Mean values was found to be 23.18. The obtained p value was <0.001 at 95% confidence interval (15.44 to 30.92)
Conclusion: In the present study, we have found that 23 out of 28 regions (82.14%) showed significant increase in bone density whereas 5 regions (17.85%) showed a decrease in bone density. DSR is a valuable tool to assess subtle radiographic changes that occur in the alveolar bone during and after orthodontic therapy and can be used to monitor the bony changes over treatment period.

KEYWORDS: Digital Subtraction Radiography, bone density, orthodontic therapy

Introduction

Early detection of periodontal bone loss is important because it provides the clinician with the basis for applying preventive or corrective measures. Reduction of alveolar crestal bone density is one early sign of periodontal disease and precedes the loss of height of the alveolar crest[1,2]. However, small changes in density cannot be reliably detected by conventional comparison of radiographs due to great variations in the anatomical structure and radiographic image density and contrast.

Orthodontic Tooth movement is known to occur either “with bone” or “through bone” [3]. When teeth are moved with bone, the amount of bone resorption on the alveolar wall in the direction of the force balances the bone formation at a certain distance from the tooth in the direction its movement, resulting in no net loss of bone [3].

However, if the pressure is increased in the PDL to a higher level, hyalinization occurs and resorption begins. Furthermore, no compensatory apposition occurs in this situation and the balance between resorption and appositition is disturbed [4], resulting in a net loss of bone.

Subtraction radiography is a technique that facilitates both qualitative and quantitative visualization of even minor density changes in bone by removing the unchanged anatomical structures from the image. This enhances the detection of bone structures with true density change, and significantly improves the sensitivity and accuracy of the evaluation.[5-7]

The widespread availability and improvement of digital dental imaging has made it easier to use digital subtraction radiography (DSR) for early disease detection and for measurement of disease progression. DSR, using serial radiographs, is a useful technique for diagnosing subtle changes in radiographic density. It has been used for the diagnosis of dental caries, destructive periodontal diseases and alveolar bone changes, and for evaluating treatment outcomes.[8-13]

DSR has also been useful in the examination of bony changes during implant healing.[14,15]
There also exists a very high correlation between the objective, quantitative assessment of subtle changes in alveolar bone by digital subtraction radiography and the true changes in bone thickness.[16]

More Recently, cone-beam computed tomography (CBCT) has also been used as another approach for evaluating bone-density changes around teeth and implants[17-22] and also during orthodontic treatment.[23]

However, CBCT examination, not being an essential procedure during orthodontic treatment, is less likely to be available for patients routinely treated by orthodontics. Pre and post operative OPGs on the other hand are routinely employed for orthodontic diagnosis and treatment planning.

The objectives of the present study were –

i. To assess retrospectively the alveolar bone density charges employing DSR before and after orthodontic treatment.

ii. To evaluate the value of DSR as a tool in assessing the bone density changes and also

iii. To test the hypothesis that orthodontic treatment enhances periodontal breakdown / detrimental to periodontal tissue integrity as assessed by evaluating the changes in bone density adopting gray scale values derived from DSR method.

Materials and Method:

A total of 14 Pre and Post operative digital image pairs were obtained from the department of Orthodontics and 28 regions were sampled and analyzed**.**

The data was retrieved from the records of patients who have completed their orthodontic treatment in the age group of 13-18 years. The mean duration of orthodontic treatment was 1.5 years. All pre and post operative radiographs were assessed at baseline and after completion of the orthodontic treatment.

The baseline preoperative and postoperative images were "matched" geometrically by the selection of common reference points using **Drop2D®** software† to compensate for any geometric and projection differences between pre and post operative films.

The "matched" baseline preoperative and postoperative images were subject to histogram equalization to eliminate contrast differences between them and then the post operative image was subtracted from the pre-operative image using **Eikona® Subtraction Radiography** software§ tool.

Changes between films were interpreted as a darkened area for loss of alveolar bone mass, a neutral gray for no change in alveolar bone mass, and a lightened area for an increase in alveolar bone mass[24].

All subtracted images were subsequently imported into **The Image Tool® software**‡ to calculate the average density of Gray levels in the areas that showed changes in subtraction.

In order to determine the changes in density in the subtracted image, this same image was set up as a reference and the value of the density of a neutral area, ie, an area that had supposedly not changed during the study such as the dental enamel was used as a "standard area". After obtaining this value, the gray values of the changed area (ROI) were provided by the **Image Tool ®** software.

A Region of Interest (ROI) was defined in the coronal third of the interproximal regions in the subtracted image. A 256 gray level was used and a value **>128** was assumed to represent a density gain in the ROI.[25]

Results

Out of 28 test regions 23 regions (82.14%) showed an increase in bone density whereas 5 regions (17.85%) showed a decrease in bone density. ***Graph 1.***

The mean bone density of the ROIs was **151.18** (gray level = 151.18 ± 19.97 SD). A one sample t test for statistical significance was carried out.

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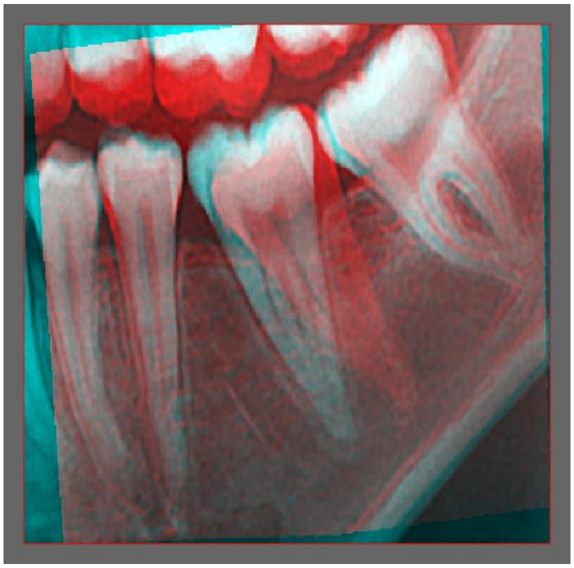


Fig 1: "Registration" (Geometric matching)of pre & post treatment radiographs

Fig 2,3: Radiographic image prior to and after orthodontic treatment (histogram equalized)

Fig 4: Subtracted image obtained from pre and post treatment matched radiographs.

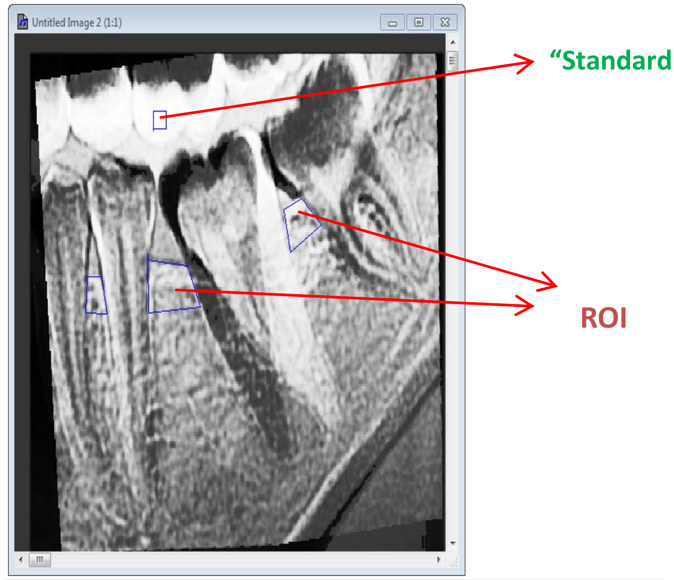
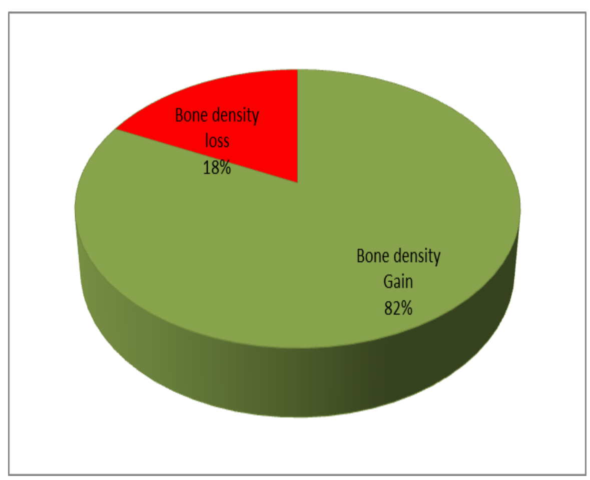


Fig 5: Analysis on subtracted image

Group	Pre- Orthodontic Treatment Group (n=28)	Post- Orthodontic Treatment Group (n=28)
Mean	**151.18**	**212.25**
SD	**19.97**	**14.03**
SEM	**3.77**	**2.65**

P<0.001 = Highly significant

Table 1: Summary of statistical analysis.



Graph 1: Percentage of sites exhibiting gain or loss of bone density

The difference of the Mean values was found to be **23.18**. The obtained p value, <0.001 at 95% confidence interval (15.44 to 30.92), is suggestive of highly significant change in alveolar bone density observed pre and post orthodontic tooth movement. ***Table 1.***

Discussion

Orthodontic forces per se are unlikely to convert gingivitis into a destructive periodontitis, but poorly executed orthodontic therapy in patients with periodontitis can easily lead to further periodontal breakdown.

Some studies have focused on the bone response to orthodontic treatment [26-30].Verna et al. [27] studied the histomorphometric bone responses during tooth movements associated with orthodontic treatment in rats. They found that the alveolar bone fraction (bone volume/total volume) was significantly decreased around displaced teeth. In addition, Bridges et al. [26] studied the effect of ages on the rate of tooth movement and mineral-density changes in rats. They found that the alveolar mineral density was significantly reduced after orthodontic treatment in both young and adult rats.

A recent systematic review performed by Bollen (2008) identified the absence of reliable evidence describing the positive effects of orthodontic treatment on periodontal health. The findings suggest that orthodontic therapy results in small detrimental effects to the periodontium. Weak evidence from one randomized study and 11 nonrandomized studies suggested that orthodontic therapy was associated with 0.03 mm of gingival recession (95% CI: 0.01–0.04), 0.13 mm of alveolar bone loss (95% CI: 0.07–0.20) and 0.23 mm of increased pocket depth (95% CI: 0.15–0.30) when compared with no treatment. The effects of orthodontic therapy on gingivitis and attachment loss were also inconsistent across studies (31).

However, orthodontic tooth movement is a stimulating factor for bone apposition [32]. It was also shown that enhanced bone healing following orthodontic movement where the defect involved periodontal structures [33]. Total bony apposition was 6.5 fold larger with the orthodontic tooth movement into the surgical bony defects in rats [32]. It has been reported that slight gentle orthodontic forces from the use of laceback ligature technique is effective in correction of bone deficient alveolar ridge [34].

Conflicting results regarding the effect of orthodontic tooth movement on periodontal healing has been described in the past. Enhance periodontal and bone regeneration by orthodontic tooth movement towards a bony defect was reported [35] . However, no such effect was also reported [36] .
On the other hand, radiographic examination is still left much to be desired as a diagnostic tool: First of all, because of frequent disagreement among evaluators on its interpretation and discrepancies of the same evaluator's interpretation at different times. Secondly, many dental lesions often progress slowly, so they cannot be easily evaluated with sequentially obtained radiographs, and thirdly, structural 'noise' produces visual confusion and limits the detection of small lesions.

Several noninvasive methods can be used to measure the alveolar bone density, including digital image analysis of microradiographs [37], dual energy x-ray absorptiometry [38,39], and ultrasound [40]. However, all of these approaches have inherent limitations, such as nonavailability of three-dimensional information and the evaluation being only qualitative. Computed tomography (CT) is one of the most useful medical image techniques for obtaining data on both the structure and density of body tissue. However, CT is not an acceptable approach for evaluating the alveolar bone density during orthodontic treatment due to its high radiation dosage, especially given that patients typically need several CT scans over several months.
The strength of Digital Subtraction Radiography (DSR) is because it cancels out the complex anatomic background, against which the subtle changes occur. As a result, the conspicuousness of the changes is greatly increased. A change in mean calcium mass per image pixel of 0.1-0.15 mg is necessary to be detected by DSR. DSR possesses high accuracy to detect small changes in calcium mass in alveolar cortical and cancellous bone.[41]

One disadvantage of digital subtraction radiography techniques, as used presently, is the need for close to identical projection alignment during the exposure of the sequential radiographs. Furthermore, highly specialized computer image processing equipment and software is required for image analyses.

In the present study, we have found that 23 out of 28 regions (82.14%) showed an increase in bone density whereas 5 regions (17.85%) showed a decrease in bone density. This can be explained due to the fact that the assessment was carried out after completion of orthodontic therapy thereby allowing sufficient time for remineralization of tissues.

The mean bone density of the chosen ROIs was 151.18 (gray level = 151.18 ± 19.97 SD). The difference of the Mean values was found to be 23.18. The obtained p value was <0.001 at 95% confidence interval (15.44 to 30.92) which concur with the findings of You-Jeong Hwang et al.[25]

However, some limitations of this study should be considered. Some previous studies have found that the measured grayscale value of an object might vary with the medical software used [42,43]; but, the values obtained with different software programs were found to be strongly correlated. Further, it is important to consider at what stage of orthodontic treatment the alveolar bone density is assessed. It is plausible that depending on the type, duration and direction of force during active tooth movement, the bone metabolism would be at varied levels determining the net bone density at the time of evaluation.

Only 14 image pairs and 28 test regions were included in this study. However, even in this sample there was significant increase of the bone density around the teeth after 12-24 months (mean = 1.5 years) of orthodontic treatment.

Only the teeth in the posterior region of the maxilla and mandible were evaluated as anterior regions in OPGs suffer from fuzziness, distortion and overlapping. Teeth with single roots should be investigated in a further study with IOPAs.

The relationship between the bone-density change and direction of tooth movements was also not investigated in this study, and the bone density around the teeth was only measured at only two time points (before institution and after completion of orthodontic treatment), with no long-term follow-up or assessment at different time intervals during various stages of orthodontic treatment.

The relation between post orthodontic increased bone density and the periodontal health need to be studied prospectively while assessing the periodontal benefits of orthodontic tooth movements. Hypothetically, increased density of alveolar bone may be more resistant to the inflammatory response elicited by plaque microorganisms, their products and its consequences, mainly bone resorption. Reports of osteoporotic individuals being more prone for enhanced bone resorption as compared to non-osteoporotics is suggestive of such a relationship [44]. Furthermore, patients with established osteoporosis are poor candidates for implant therapy [45]. Hence, more extensive studies are required to understand in depth the bone changes brought about by orthodontic therapy and its impact on periodontal status on long-term basis.

Conclusion

- Within limitations of this study, we conclude that orthodontic tooth movement can significantly increase radiographic alveolar bone density as demonstrated through the use of digital subtraction radiography.

- DSR is a valuable and sensitive tool in assessing the bone density changes and also the hypothesis that orthodontic treatment enhances periodontal breakdown (is detrimental to periodontal tissue integrity) is questionable and perhaps on the contrary leads to an increased bone density as assessed by evaluating the changes in bone density adopting gray scale values using DSR.

References

1. Jeffcoat MK, Kaplan ML, Goldhaber P. Predicting alveolar bone loss in beagles using bone-seeking radiopharmaceutical uptake. J Dent Res 1980;59:844-848.

2. Waerhaug J. The angular bone defect and its relationship to trauma from occlusion and downgrowth of subgingival plaque. J Clin Periodontol 1979;6:61-82.

3. Melsen B (1999) Biological reaction of alveolar bone to orthodontic tooth movement. Angle Orthod 69:151-158

4.Verna C, Zaffe D, Siciliani G (1999) Histomorphometric study of bone reactions during orthodontic tooth movement in rats. Bone 24:371-379

5. Rüttimann UE, Okano T, Gröndahl H-G, Gröndahl K, Webber RL. Exposure geometry and film contrast differences as bases for incomplete cancellation of irrelevant structures in dental subtraction radiography. SPIE Digital Radiography 1981;314:372-377.

6. Gröndahl H-H, Gröndahl K. Subtraction radiography for the diagnosis of periodontal bone lesions. Oral Surg Oral Med Oral Pathol 1983;55:208-213.

7. Wenzel A, Warrer K, Karring T. Digital subtraction radiography in assessing bone changes in periodontal defects following guided tissue regeneration. J Clin Periodontol 1992;19:208-213.

8. Webber RL, Ruttimann UE, Gro¨dahl HG. X-ray image subtraction as a basis for assessment of periodontal changes. J Periodontal Res 1982;17:509-11.

9. Reddy MS. Radiographic methods in the evaluation of periodontal therapy. J Periodontol 1992;63:1078-84.

10. Tyndall DA, Kapa SF, Bagnell CP. Digital subtraction radiography for detecting cortical and cancellous bone changes in the periapical region. J Endod 1990;16:173-8.

11. Kravitz LH, Tyndall DA, Bagnell CP, Dove SB. Assessment of external root resorption using digital subtraction radiography. J Endod 1992;18:275-84.

12. Grondahl HG, Gro¨ndahl K, Okano T, Webber RL. Statisticalcontrast enhancement of subtraction images for radiographic caries diagnosis. Oral Surg Oral Med Oral Pathol 1982;53:219-23.

13. Nummikoski PV, Martinez TS, Matteson SR, McDavid WD, Dove SB. Digital subtraction radiography in artificial recurrent caries detection. Dentomaxillofac Radiol 1992;21:59-64.

14. Jeffcoat MK, Reddy MS, van den Berg HR, Bertens E. Quantitative digital subtraction radiography for the assessment of peri-implant bone change. Clin Oral Implants Res 1992;3: 22-7.

15. Reddy MS, Mayfield-Donahoo TL, Jeffoat MK. A semiautomated computer-assisted method for measuring bone loss adjacent to dental implants. Clin Oral Implants Res 1992;3:28-31.

16. M Christgau, K A Hiller, G Schmalz, C Kolbeck, A Wenzel. Quantitative digital subtraction radiography for the determination of small changes in bone thickness: an in vitro study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998 Apr ;85 (4):462-72.

17. de Oliveira RC, Leles CR, Normanha LM, Lindh C, Ribeiro-Rotta RF (2008) Assessments of trabecular bone density at implant sites on CT images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 105:231-238

18. Norton MR, Gamble C (2001) Bone classification: an objective scale of bone density using the computerized tomography scan. Clin Oral Implants Res 12:79-84

19. Shahlaie M, Gantes B, Schulz E, Riggs M, Crigger M (2003) Bone density assessments of dental implant sites: 1. Quantitative computed tomography. Int J Oral Maxillofac Implants 18:224-231

20. Shapurian T, Damoulis PD, Reiser GM, Griffin TJ, Rand WM (2006) Quantitative evaluation of bone density using the Hounsfield index. Int J Oral Maxillofac Implants 21:290-297

21. Turkyilmaz I, Tozum TF, Tumer C (2007) Bone density assessments of oral implant sites using computerized tomography. J Oral Rehabil 34:267-272

22. Aranyarachkul P, Caruso J, Gantes B, Schulz E, Riggs M, Dus I, Yamada JM, Crigger M (2005) Bone density assessments of dental implant sites: 2. Quantitative cone-beam computerized tomography. Int J Oral Maxillofac Implants 20:416-424

23.Hsu JT, Chang HW, Huang HL, Yu JH, Li YF, Tu MG. Bone density changes around teeth during orthodontic treatment. Clin Oral Investig. 2010 Apr 15.

24.Danesh-Meyer MJ, Chen ST, Rams Te. Digital subtraction radiographic analysis of GTR in human intrabony defects. Int J Periodontics Restorative Dent. 2002;22(5):441-9

25.You-Jeong Hwang et al. Effect of Scaling and Root Planing on Alveolar Bone as Measured by Subtraction Radiography. Journal of Periodontology, Sep. 2008, Vol. 79, No. 9, Pages 1663-1669

26. Bridges T, King G, Mohammed A (1988) The effect of age on tooth movement and mineral density in the alveolar tissues of the rat. Am J Orthod Dentofacial Orthop 93:245-250

27. Verna C, Zaffe D, Siciliani G (1999) Histomorphometric study of bone reactions during orthodontic tooth movement in rats. Bone 24:371-379

28. Melsen B (1999) Biological reaction of alveolar bone to orthodontic tooth movement. Angle Orthod 69:151-158

29. Melsen B (2001) Tissue reaction to orthodontic tooth movement--a new paradigm. Eur J Orthod 23:671-681

30. Verna C, Melsen B (2003) Tissue reaction to orthodontic tooth movement in different bone turnover conditions. Orthod Craniofac Res 6:155-163

31. Bollen AM. Effects of malocclusions and orthodontics on periodontal health:evidence from a systematic review. J Dent Educ. 2008;72:912–8

32.Vardimon A, Nemcovsky C, Dre E. Orthodontic tooth movement enhances bone healing of surgical bony defects in rats. J Periodontol. 2001;72:858–864.

33.Nemcovsky C, Beny L, Shanberger S, Feldman-Herman S, Vardimon A. Bone apposition in surgical bony defects following orthodontic movement: a comparative histomorphometric study between root- and periodontal ligament-damaged and periodontally intact rat molars. J Periodontol. 2004;75:1013–1019.

34.Hibino K, Wong RW. Orthodontic tooth movement enhancing bony apposition in alveolar bony defect: a case report. Case Journal. 2009;2:116.

35.Nevins M, Wise R: Use of orthodontic therapy to alter infrabony pockets. 2. Int J Periodontics Restorative Dent 1990, 10:198-207.

36. Wennström J, BL BS, Nyman S, Thilander B: Periodontal tissue response to orthodontic movement of teeth with infrabony pockets. Am J Orthod Dentofacial Orthop 1993, 103:313-319.

37. Jager A, Radlanski RJ, Taufall D, Klein C, Steinhofel N, Doler W (1990) Quantitative determination of alveolar bone density using digital image analysis of microradiographs. Anatomischer Anzeiger 170:171-179

38. Drage NA, Palmer RM, Blake G, Wilson R, Crane F, Fogelman I (2007) A comparison of bone mineral density in the spine, hip and jaws of edentulous subjects. Clin Oral Implants Res 18:496-500

39. Oltramari PV, Navarro Rde L, Henriques JF, Taga R, Cestari TM, Janson G, Granjeiro JM
(2007) Evaluation of bone height and bone density after tooth extraction: an experimental study in minipigs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 104:e9-16

40. Al Haffar I, Padilla F, Nefussi R, Kolta S, Foucart JM, Laugier P (2006) Experimental evaluation of bone quality measuring speed of sound in cadaver mandibles. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 102:782-791

41. M Christgau, K A Hiller, G Schmalz, C Kolbeck, A Wenzel. Accuracy of quantitative digital subtraction radiography for determining changes in calcium mass in mandibular bone: an in vitro study. J Periodontal Res. 1998 Apr ;33 (3):138-49

42. de Oliveira RC, Leles CR, Normanha LM, Lindh C, Ribeiro-Rotta RF (2008) Assessments of trabecular bone density at implant sites on CT images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 105:231-238

43. Lagravere MO, Carey J, Ben-Zvi M, Packota GV, Major PW (2008) Effect of object location on the density measurement and Hounsfield conversion in a NewTom 3G cone beam computed tomography unit. Dentomaxillofac Radiol. 37:305-308

44. Hidebolt C F (1997) Osteoporosis and oral bone loss. Dentomaxillofac. Radiol 26 :3-15.

45. EC Gaetti-Jardim, JF Santiago-Junior, MC Goiato, EP Pellizer, O Magro-Filho, EG Jardim. (2011) Dental Implants in Patients With Osteoporosis. Journal of Craniofacial Surgery 22:3, 1111-1113.